

Radiation Level in the Intersection Region of AP2 and 8GeV Beam-line due to Beam loss in the AP2 Beam-line

C.M. Bhat and P. Martin

Fermi National Accelerator Laboratory

P.O. Box 500, Batavia, Illinois 60510*

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Recently a question has been raised regarding the access to the 8 GeV beam-line tunnel (beam-line from the Fermilab Booster to the FMI which is under construction) near the intersection of the 8 GeV and the AP2 beam-line tunnels during the stacking of pbars or when the AP3 beam-line is in use for the Accumulator or Debuncher studies. In this note we address this question and suggest possible solutions.

During the next fixed target run at Fermilab, the 120 GeV proton beam from the Main Ring will be used to produce pbars for E868 experiment. At the same time the installation of the 8 GeV proton beam-line instrumentation and/or the installation of the FMI will take place. But the 8 GeV pbar beam-line (AP2 beam-line) and the 8 GeV beam-line tunnel will intersect one above the other. The soil thickness between these two beam lines in the region of intersection is only about 1.37 m. Hence any accidental beam loss in AP2/AP3 beam line will increase the radiation dose level in the 8 GeV proton beam-line tunnel. During the installation of the instrumentations for the 8 GeV beam-line, there will be the FMI-construction/accelerator personnel working in the tunnel. Hence it is essential to estimate the radiation dose level in the 8 GeV beam-line and to ensure that the total radiation dose received by these personnel is within the safety limits.

A schematic view of the region of the AP2 beam-line and the 8 GeV beam-line is shown in Fig. 1. In the AP2 beam-line tunnel there are two beam lines viz., AP2 and AP3 beam-lines. Both of these beam lines are at about 1.8 m (6 ft) from the tunnel floor. The tunnel floor of the 8 GeV proton beam-line is at an elevation of 217.4748 m (713.5 ft) at the location where it intersects the AP2 beam line. They cross at an angle of about 49° . The floor of AP2 beam line tunnel is at 221.2848 m (726 ft) elevation with 1.3716 m soil in between the two beam line tunnels. Previously we have decided to replace 0.3048 m (1 ft) of this soil with shielding steel to provide the required shielding between the 8 GeV line and the surface. However, this steel is placed in a manner which does not provide full coverage for the conditions being addressed here, and is therefore neglected in this discussion.

To estimate the radiation levels in and around the 8GeV beam-line tunnel we make the following assumptions:

- The maximum number of protons @120GeV on the pbar target is $4E12/2.5$ sec.

All negatively charged particles produced in the target, lying in a 4% momentum acceptance at 8GeV will be transported through the AP2 beam line.

- The maximum number of protons @8GeV in the AP3 beam-line is 3.6E13/hour.

The normal operational beam loss in AP2/AP3 beam lines is assumed to be negligible while the accidental beam losses are responsible for high radiation level in the 8 GeV beam line tunnel. We define an ‘accidental beam loss’ as continuous loss of all beam particles at one point for one hour. Our goal is to have radiation dose level for accidental losses smaller than 1.0 mrem/accident in the region where accelerator personnel can have access. The guide-lines to determine the acceptable radiation levels are taken from the FERMILAB RADIOLOGICAL CONTROL MANUAL.

Beam Loss in the AP2 and AP3 Beam-lines

Beam in the AP2 beam-line is mixture of 8GeV pbars, π^- and K^- . A schematic diagram of the pbar beam collection system is shown in Fig. 2. The total angular acceptance of the Li- lens is about 2.6° . Using the calculated data from Ref. 1 for copper target and extrapolating to 120GeV we found,

the total number of π^- per 120GeV proton = 0.021.

The K^- production cross section is about 10% of π^- production cross section (Private communication with A. Ginneken). Hence we expect,

the total number of K^- per 120GeV proton = 0.0021.

From pbar production cross-section (C.Hojvat and A. Ginneken, Nucl.Inst. Methods Vol. 206(1983) 67) we expect,

the total number of pbar per 120GeV proton = 4.9E-5.

The π^- flux is therefore the dominant one in the AP2 beam-line. The total transported beam in the AP2 beam-line during the pbar stacking will be about 8E10/pulse. Hence during an accidental condition we can expect up to 1.2E14 π^- /accident in the vicinity of the intersection.

Occasionally 8GeV beam from the Main Ring will be transported through the AP3 beam-line for Accumulator and Debuncher studies. Depending upon the mode of operation of the Debuncher and Accumulator rings, different beam intensities are used. The operational modes and the corresponding beam intensities are shown in Table I. The maximum beam transported during these studies can be about 3.6E13p/hour. Any accidental beam loss during this period implies 3.6E13p/accident.

Radiation Dose in The 8 GeV Beam-line Tunnel

High energy interactions of beam particles with beam-line elements results in a hadronic shower peaking in the forward direction. Therefore, to evaluate the radiation dose at a location near the beam-line one has to assume the radiation source point to be sufficiently up-stream of the point of interest. In the present case we assume that the beam is lost at about 7 - 8 m up-stream of the intersection of the two beam-lines. We have looked into two scenarios for beam loss : 1) point beam loss and 2) beam loss due to scraping. The latter acts as an extended source and gives rise to about an order of magnitude less radiation than the point source. Hence, only the results from the point source loss are presented here.

The 8 GeV beam-line is fairly straight in this region. There are two exits on both sides of the intersection; one is at about 36 m up-stream of the intersection and another is at about 57 m down-stream of the intersection (MI-8 Service Building with an alcove and labyrinth). We have estimated the radiation dose at the exits by carrying out Monte Carlo calculations using the code CASPEN (Ref. 2). The geometry of the whole problem is treated as a culvert. A schematic view of the geometry used in the Monte Carlo calculations is shown in Fig.3. By extrapolating the calculated results we have estimated the radiation levels in the tunnel near these exits to be far less than 1.0 mrem/accident. However, right under the intersection point we expect radiation levels over 5.0 rem/accident. The estimated radiation levels near the exits for different beam conditions are listed in Table I

Suggestions:

To avoid any accidental exposure of personnel to high radiation doses we suggest the following:

Temporary interlock gates can be installed near the exits. These gates will be secured when there is beam in the AP2/AP3 beam line. With this we can bring down the accidental radiation exposure to less than 1.0 mrem/accident.

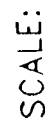
Reference

1. H. Grote, R. Hagedorn and J. Ranft, 'Atlas of Particle Production Spectra'
2. V. A. Ginneken, Monte Carlo Code CASPEN

Table I. The maximum beam loss in AP2/AP3 beam line and the radiation dose in the 8GeV beam-line tunnel. The radiation doses presented here are obtained from Monte Carlo calculations with CASPEN2. (A continuous beam loss for one hour at a point in the beam line is taken to be an accidental beam loss).

Beam-line and Type of Beam	Max. Beam-loss /accident	Max. Rad. Dose near exits(mr/acc.)
AP2 beam-line, $\pi^- + K^- + \text{anti-proton}$ (Beam injection to Debuncher)	1.2E14	0.17 (A) 0.01 (B)
AP2 beam-line, forward protons (Beam injection to Debuncher)	3.6E13	0.085 (A) 0.001 (B)
AP3 beam-line, reverse proton (Beam injection to Accumulator)	3.6E13	0.085 (A) 0.001 (B)
AP2 beam-line, $\pi^+ + K^+ + \text{protons(secondary)}$ (Beam injection to Debuncher and proton staking)	1.2E14 *	0.17 (A) 0.01 (B)
AP2 beam-line,reverse proton (Beam from Debuncher towards pbar) Target	1E11	$\ll 0.001$ (A) $\ll 0.001$ (B)

A - Near the EXIT STAIRS, B - Near the Alcoves and Labyrinth, * - In this case the 8 GeV π^+ dominates over the K^+ or the secondary protons. The the number of secondary 8 GeV protons/120 GeV proton is about $3.5E-5$. The maximum beam intensity on the pbar target is $4E12p/pulse @120$ GeV (private communication with E. Harms Aug-1995).



Standard Fermilab Geometry for the \bar{p} Target and \bar{p} Collection System

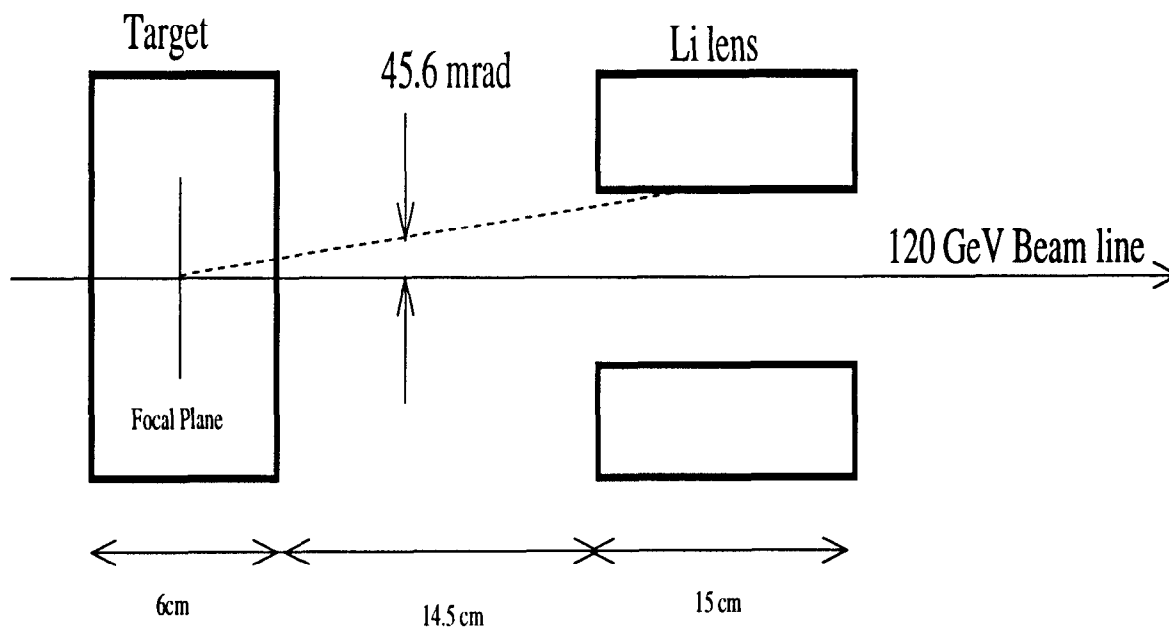


Figure 2: A schematic view of the \bar{p} collection system. The 8 GeV \bar{p} bending magnet is not shown.

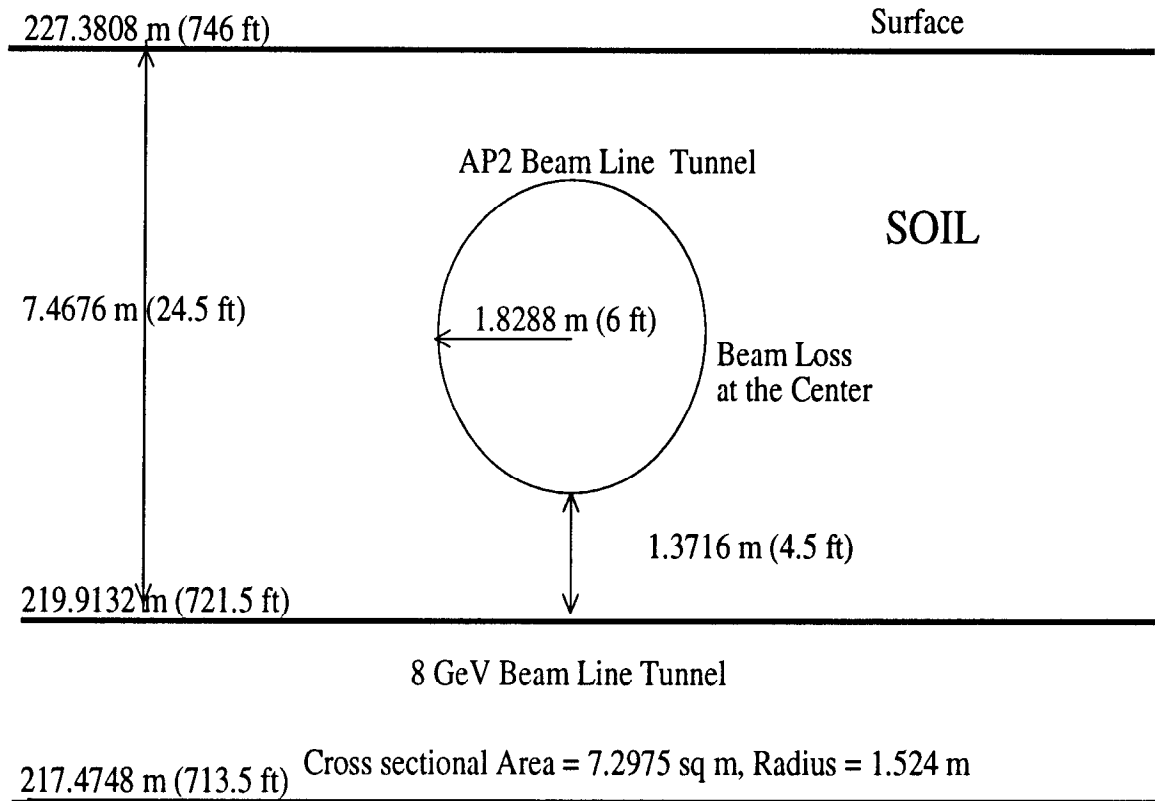


Figure 3: Geometry used in the Monte Carlo calculations to estimate the radiation dose in 8 GeV beam line tunnel due to an accidental beam loss in the AP2/AP3 beam line.

The rms width r_m of the beam is related to the source radius by the relationship

$$r_m = \frac{r_s}{2} \quad (8)$$

In the case of this example, the values of the rms beam size and divergence from such a source have been calculated and are summarized in table 4.

Table 4: Values of kinematic and beam parameters for the proton gun.

Parameter	Value
Kinetic Energy (keV)	12.351
Beam Current (nA)	60-600
Normalized RMS Emittance (π mmmr)	0.000436
Plasma Temperature ($^{\circ}$ K)	300
Source Effective Radius (μ m)	41.5
RMS Transverse Velocity Spread (m/s)	1575
RMS Transverse Beam Size (μ m)	20.75

Optics

Now that the proton source has been determined, it is time to apply the envelope equation (1) to calculate the rms beam size as a function of distance down the beam line. This calculation will determine the number and strength of required focussing lenses.

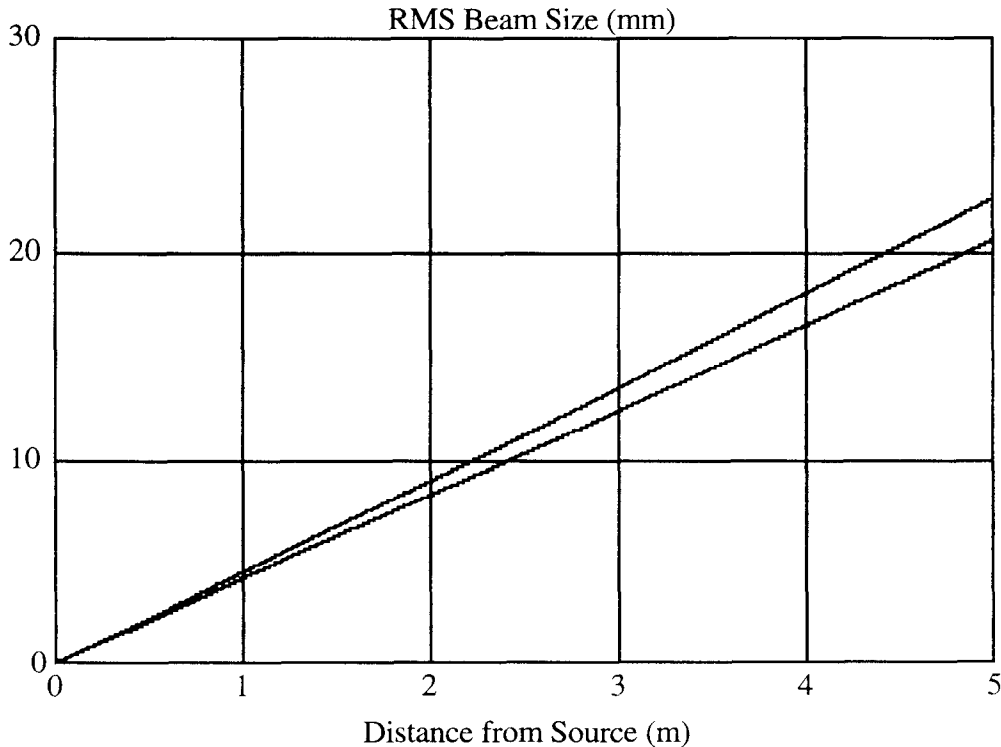


Figure 2: Calculation of the zero current (lower curve) and 600 nA proton beam (upper curve) rms beam size vs. distance from the source.

A dedicated computer program was written to evaluate the envelope equation. As a check, this program also calculated Twiss parameters and propagated the zero current beam size evolution. The first result of this program appears in figure 2. Using the starting values in table 4 for emittance and initial rms beam radius, a 600 nA proton beam is compared with the expected evolution of a zero current beam. The curve for the 60 nA proton beam is virtually identical to the zero current case.

When the beam reaches a rms radius of 2 cm, assume that an infinitesimally narrow focussing solenoid is used to focuss the protons into a parallel beam. The computer program was then asked to simulated the evolution of the beam size with distance. The result is shown in figure 3 for a 600 nA beam current. As before, the zero current expectation is also plotted. As in the case of beam size evolution away from the source, the curve for the case of a 60 nA beam current is indistiguishable from the zero current situation.

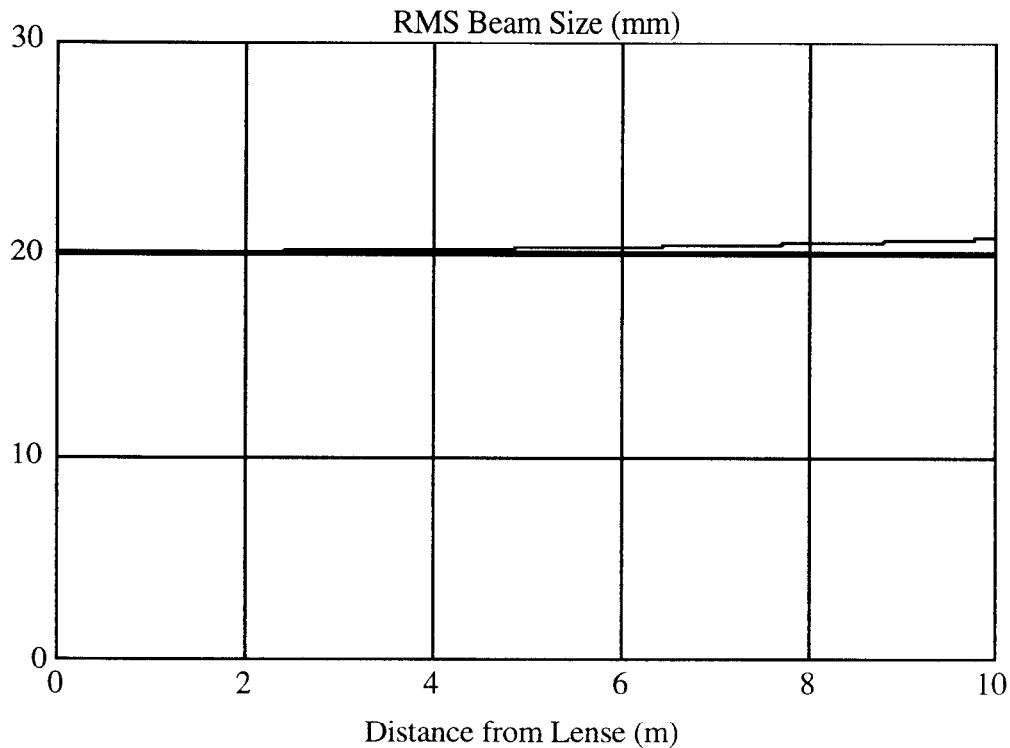


Figure 3: Calculation of the zero current (lower curve) and 600 nA proton beam (upper curve) rms beam size vs. distance from a lense for which the exiting protons are focussed into a parallel beam.

Instrumentation

The mission of phase 1 is to confirm calculations of beam size evolution through the optical system. Therefore, a monitor capable of measuring the beam profile is required. Because of the low energy of the protons, a Faraday-based profile monitor will be constructed. To allow measurement of the evolution of the beam size with distance down the pipe, the profile monitor will be designed to travel up and down the vacuum chamber, which is envisioned to be 6" O.D. electropolished stainless steel tubing. Shown in figures 4 and 5, this monitor has three outputs. The first two are the currents on the horizontal

and vertical wires. The third is the current on the Faraday plate which terminates the beam. There are 3 degrees of freedom on this roving mechanism. The first two are the motion of the forks which move the sensor wires. The third is the motion of the detector up and down the vacuum chamber.

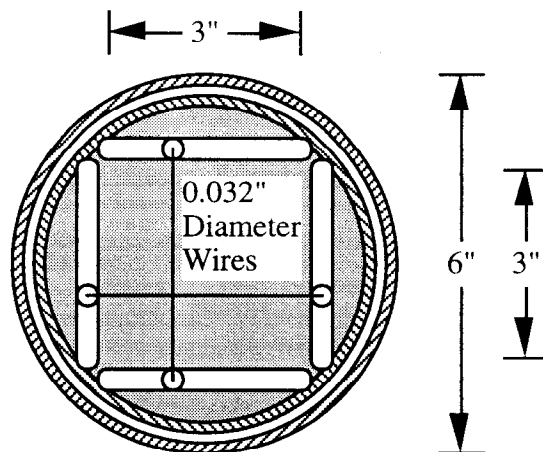


Figure 4: Beam eye view of the roving profile monitor. The horizontal and vertical wire are mounted on rotating fork arms which rotate across a 3" chord.

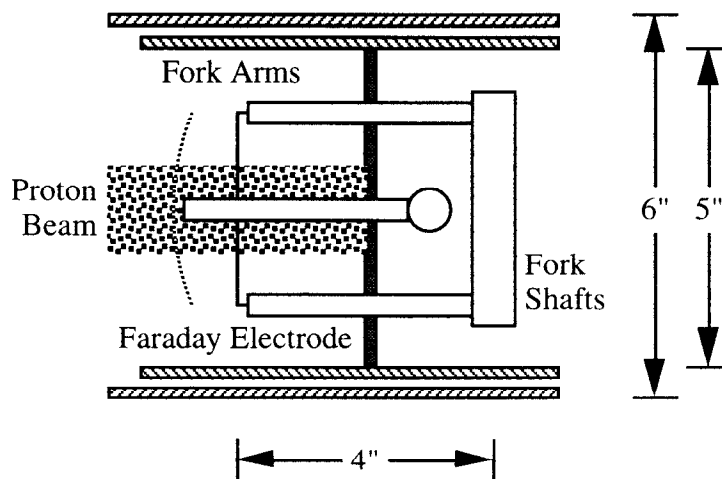


Figure 5: Side view of the roving profile monitor. The beam is terminated on a Faraday plate which, along with the two wires, simultaneously give the horizontal profile, vertical profile, and the beam current.

If the beam current I_b is 600 nA and the rms beam radius σ_b is 2 cm, a wire of diameter d_w approximately equal to 1 mm will sense a peak current I_w of

$$I_w = \frac{d_w}{\sqrt{2\pi} \sigma_b} I_b \quad , \quad (9)$$

or 12 nA. If a dynamic range of 100:1 is desired to fully describe the density distribution, a current resolution of 120 fA is required. There are circuits which can easily handle such currents.

Sub-Phases

In order to attain the goals outlined for phase 1, a number of intermediate goals or configurations or sub-phases can be identified.

Phase 1.1: Proton gun delivering beam into a 6 m long drift. The drift is terminated by the roving Faraday-based profile monitor. If all goes well, first beam should be measured in mid-September 1995.

Phase 1.2: Focussing the protons into a parallel beam with a short solenoid lens. The protons are again intercepted by the roving profile monitor. This sub-phase should begin in early October 1995.

Phase 1.3: Bending the protons twice by 90° . The protons are again intercepted by the roving profile monitor. The schedule calls for this sub-phase starting in mid-October 1995.

Radiation Dose in the 8GeV Beamline due to
Accidental Beamlosses in the AP2/AP3 Beamline (CASPEN)
(Direction of the Beams: pbar target to Debuncher ring)

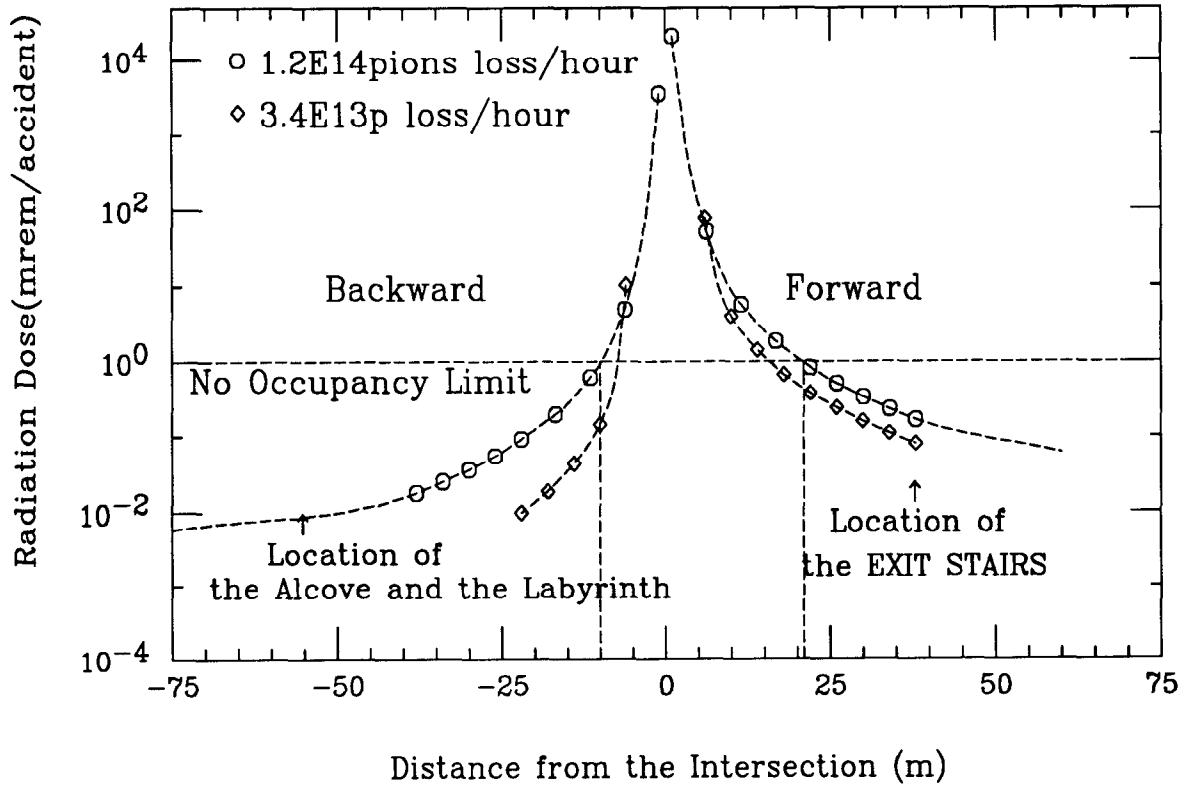


Figure 4: Results of the Monte Carlo calculations with computer code CASPEN for protons and pions. The locations of the EXITs (from the 8 GeV beam-line) which are on the both sides of the intersections are indicated by arrows. The origin is the point of intersection of two beam lines.